KOPIO TN136
Signal losses and detector integration

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Abstract

Additional signal losses incurred by the present design are estimated using the FastMC. With a realistic assessment of the active area of the PR and the vacuum tank, flanges and beam pipe, there is an approximately 44% loss of the signal yield with 2γPR detection method. For the baseline review, a loss of only 14% was assessed.

1 Introduction

In this note I address these detector or geometry issues that result in loss of signal that were overlooked or put aside for the April 2005 Baseline review:

- No active PR on the sides of the beam pipe,
- The vertical size of the PR inactive region near the beam, and
- The effect of flanges and other support structure.

The basis for the results in this note are the FastMC simulation [1] of the "baseline" detector as described in `http://www.phy.bnl.gov/~djaffe/KOPIO/Baseline/baseline.html`. The detector dimensions are given in Table 1.

2 Assessing the losses

2.1 Method for quoting the loss

Since we use a likelihood method that gives a range of signal yields, there is no single 'standard' set of cuts that defines a 'standard' signal yield. To summarize the results, I evaluate the loss factor, L_i, for twelve or thirteen specific likelihood cuts where $\text{yield(new)}_i = L_i \times \text{yield(old)}_i$. The specific likelihood cuts have been defined to give signal yields from ~ 10 to ~ 150 events for the 2γPR detection method. The results are summarized as $\tilde{L} \pm \delta L$ where $\tilde{L} \equiv$ median of $\{L_i\}$ and $\delta l \equiv (\max(L_i) - \min(L_i))/2$. **Note that $\tilde{L}$ is NOT the mean and δl is NOT the standard deviation.**

X halfwidth	Y halfwidth	Z at US end	Z at DS end	Volume name
92.50	8.25	-10.0	997.0	Beam pipe
127.00	127.00	997.0	1397.0	Decay vol
150.00	150.00	1397.0	1531.0	Pre-Rad
220.00	220.00	1531.0	1601.0	Calorim
92.50	8.25	1397.0	1601.0	DS hole
200.00	50.00	1601.0	2596.0	CatchrVol
150.00	15.00	2596.0	2596.0	Catcher detector (special)

Table 1: FastMC definition of the baseline detector. Units are centimeters. The "DS hole" is interpreted as the the inner limits of the PR active area in the FastMC.

Loss $\tilde{L} \pm \delta L$	Comment
0.9607 ± 0.0241	Exclude γ into sides of PR
0.7270 ± 0.0689	Exclude γ through beam pipe
0.7170 ± 0.0589	Exclude γ through beam pipe and sides of PR

Table 2: Median loss and half-range (see text for definition) when photons into the PR on the sides of the beam pipe are excluded and/or when photons that traverse the beam pipe and enter the PR are excluded. The inner aperture half-size of the PR is 8.25 cm in y for these results as described in Table 1. These results are for the 2γPR detection method only.

2.2 Loss due to no active PR on sides of beam

Table 2 shows the loss in signal yield for the baseline detector for the 2γPR detection method when there is no active PR on the sides of the beam hole. In addition the loss in yield is shown when photons that traverse the beam pipe and enter the PR are excluded. There is a 4% reduction of the signal yield if there is no active PR on the sides of the beam.

2.3 Loss due to change in active area of PR

For the baseline detector, the active area of the PR was assumed to extend to within 8.25 cm of the beam in y. This is incorrect. A more realistic evaluation [2] gives an active area that extends to within 16 cm of the beam in y. See Table 3 for details. The loss in yield is $\tilde{L} = 0.7980 \pm 0.0085$ for the 2γPR detection method. The yields are evaluated assuming no active PR on the sides of the beam. This result is consistent with the more comprehensive study described in TN135 [4].

2.4 Loss due to vacuum tank and flanges

For these studies the active area of the PR begins at 16 cm in y from the center of the beam and there is no PR on the sides of the beam pipe.

The loss of signal due to the vacuum tank and beam pipe was given in the CDR as

Inner diameter of vacuum pipe	10 cm
Thickness of vacuum pipe	0.5 cm
Gap	0.5 - 1.0 cm
PR edge to active region	5 cm

Table 3: Evaluation of the inner limit of the active area of the PR in y with respect to the center of the beam. Assuming a gap of 0.5 cm gives a PR active area starting at 16 cm from the center of the beam.

Component	z-offset	z-extent	Thickness
BARREL FLANGE	101.6000	14.1072	2.5400
BARREL FLANGE	101.6000	6.3500	11.5697
Component	radial offset	radial extent	Thickness
TRANSITION FLANGE	99.6950	3.2512	1.9050
Component	x halfwidth	y halfwidth	Thickness
PIPE FLANGE	106.6800	30.4800	2.5400
Component	Side thickness	Top/bottom thickness	
DS BEAM PIPE	0.9525	0.3175	

Table 4: The nominal positions and thicknesses of flanges and beam pipes as simply represented as a cylinder in the FastMC (See Figure 2). The z-offset is the distance from each endcap to the center of the barrel flange. The radial offset is the radial distance from the beam line to center of the transition flange. The pipe flange is taken to be rectangular in the xy plane. In the current design it is octagonal — a rectangle with the corners chopped off. The vacuum tank thickness is taken to be 0.635 cm (1/4"). All dimensions in the table are in centimeters.

0.86 based on TN024 [3]. I follow the same analysis technique as in TN024 and calculate the amount of material traversed based on the trajectories of the photons from signal π^0 decays. The loss per photon was calculated using the photon attenuation length for Al as a function of photon energy [5]. I assume that all processes contributing to attentuation, primarily pair production and Compton scattering, result in loss of the photon as signal [6].

The current design of the vacuum tank, flanges and beam pipe are shown in Figure 1. The caption of Figure 1 contains the naming scheme used to distinguish the different flanges. In the FastMC the vacuum tank is taken to be a cylinder and the beam pipe is taken to be rectangular; the tank and flanges as approximated in the FastMC are shown in Figure 2 and given in Table 4.

To calculate the material traversed, a photon trajectory is extrapolated to the wall of the vacuum tank. If the extrapolated position is within the radial- or z-extent of a flange, then it is assumed that the photon traversed the full thickness of the flange with the calculated incidence angle. In other words, photons cannot clip the corner of a flange. The calculated single photon attenuation as a function of "position on detector" [7] is shown in Figure 3.

Table 5 and Table 6 show the effect of the tank, individual flanges and the beam pipe

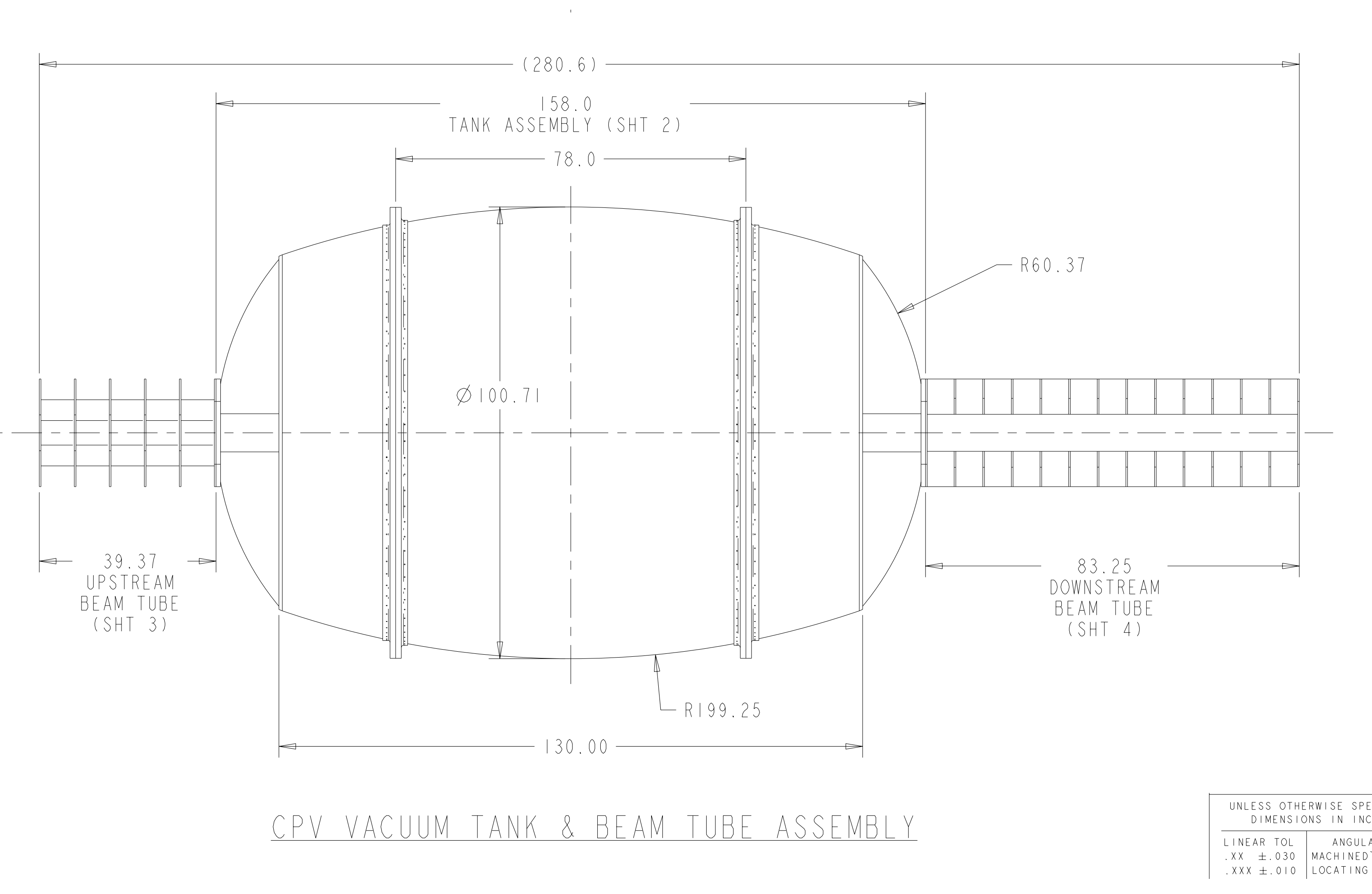

Figure 1: This is a portion of sheet 1 of drawing A98-01321 of the "KOPIO CPV VACUUM TANK AND BEAM TUBES" by Advanced Energy Systems Inc. Dimensions are in inches. The flanges making the transition from the more spherical dome to the more cylindrical tank separated by 130" are dubbed the "Transition Flanges". The larger flanges on the cylinder separated by 78" are dubbed the "Barrel Flanges" The flanges at the point where the tank meets the beam pipe separated by 158" are dubbed the "Pipe Flanges".

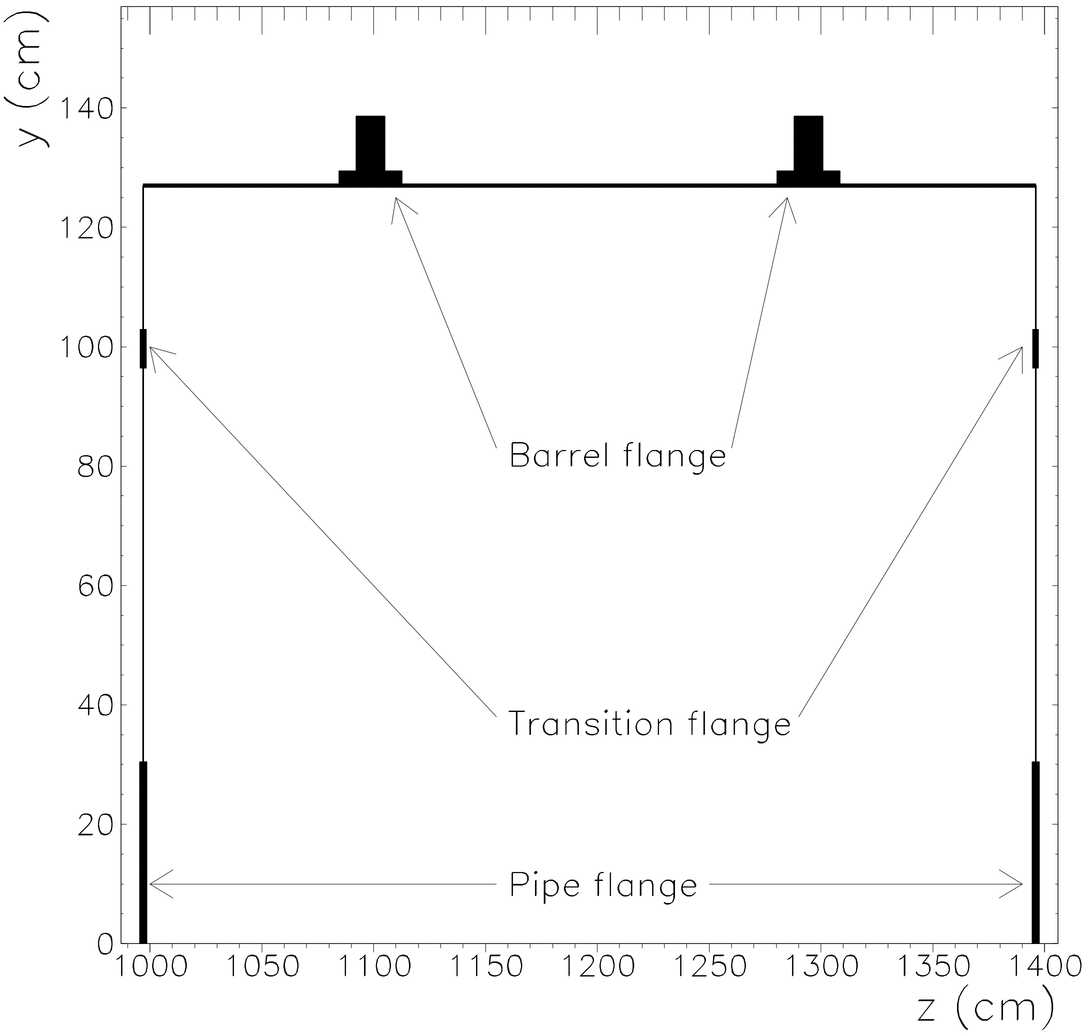

Figure 2: The representation of the vacuum tank and flanges used in the FastMC. The aperture of the beam pipes is not shown.

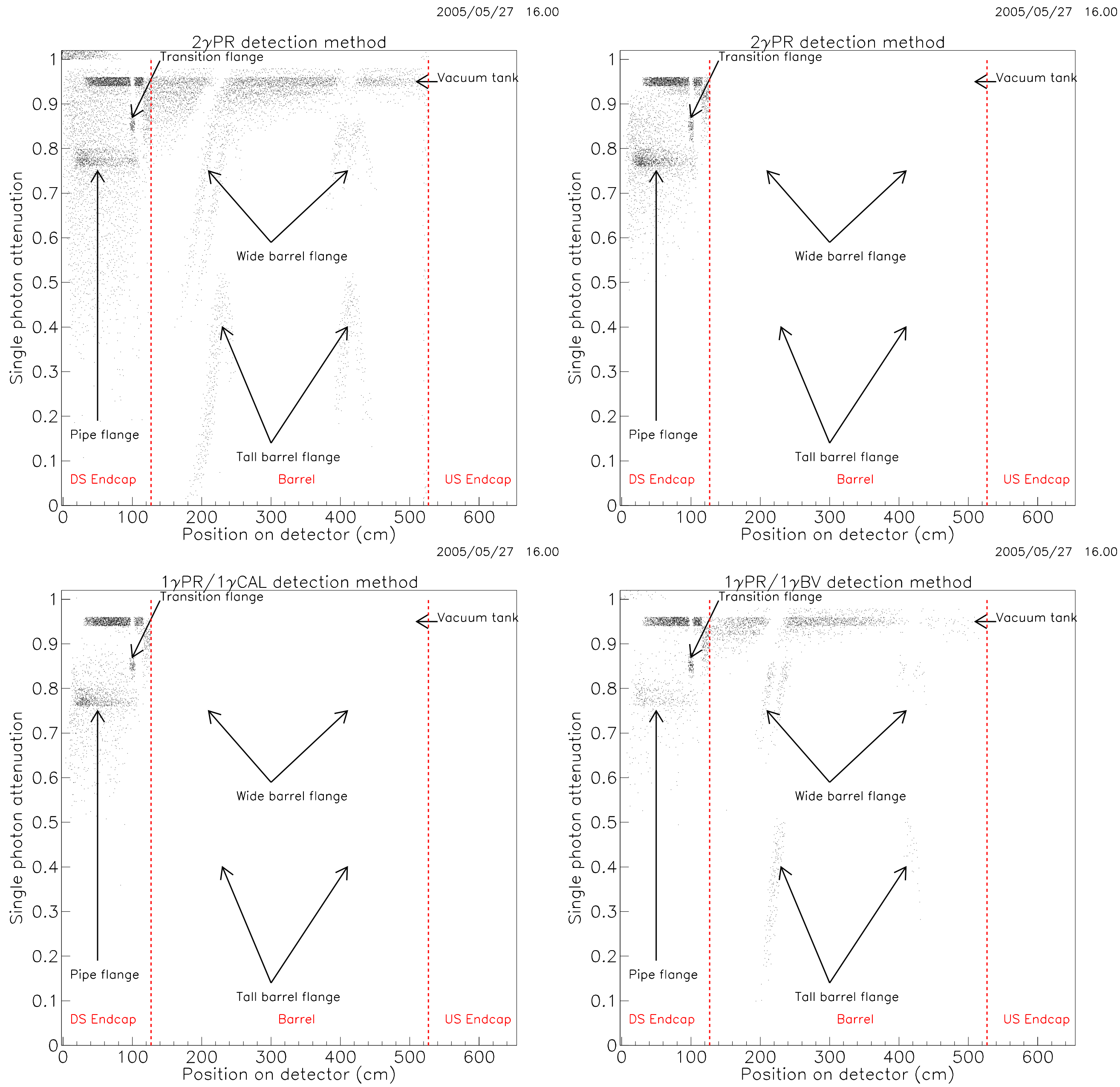

Figure 3:
Top left: single photon loss due to the vacuum tank, flanges and beam pipe as a function of "position on detector" [7]. The effect of various elements is labelled in the plot. The fuzzy region below the band labelled "Vacuum tank" for the DS Endcap is due to the beam pipe.
Top right: single photon loss due to the vacuum tank, flanges and beam pipe after applying the 2γPR geometric acceptance criteria.
Bottom left: single photon loss due to the vacuum tank, flanges and beam pipe after applying the 1γPR/CAL geometric acceptance criteria.
Bottom right: single photon loss due to the vacuum tank, flanges and beam pipe after applying the 1γPR/BV geometric acceptance criteria.

for the three detection methods assuming that the tank is composed of pure aluminum. For the 2γPR detection method, the loss for the tank and beam pipe of 0.848 ± 0.007 is consistent with the 0.86 assumed in the CDR. The overall signal loss is most profound for the 1γPR/CAL and 2γPR methods mainly due to the losses in the beam pipe and pipe flange. The 1γPR/BV method is more sensitive to the thickness of the tank and barrel flange. From Table 6, the reduction in yield due to the tank alone varies from 7% to 9%. The reduction in yield due to the beam pipe alone is $\sim$7%, $\sim$14% and $\sim$1% for the 2γPR, 1γPR/CAL and 1γPR/BV detection methods, respectively. The reduction in yield due to pipe flange alone is $\sim$8%, $\sim$6% and $\sim$2.5% for the 2γPR, 1γPR/CAL and 1γPR/BV detection methods, respectively. The transition flange alone results in $\sim$1% or less reduction in signal for all detection methods. The total reduction in the yield of the 1γPR/BV detection method due to the barrel flange is $\sim$6%.

Additional studies were done with using attenuation tables generated for the aluminum/copper alloy defined in Table 7 that is currently being envisioned for the tank, flanges and beam pipe [8]. Figure 4 shows the the relative yield as a function of the relative thickness of the tank, flanges and beam pipe for the three detection methods assuming all materials were the aluminum alloy.

The last row in Table 5 shows that replacement of pure aluminum with the aluminum alloy for the tank, flanges and beam pipe results in a reduction of signal yield of 2.2% to 3.6%.

The effect of the charged particle veto (CPV) scintllators, support structure, phototubes, bases and cables was ignored for the results presented above. The expected mass of the CPV is listed in Table 8. Assuming a cylinder of length 400 cm and radius 127 cm with the CPV mass distributed uniformly over the surface gives a thickness range of 0.618 to 0.927 g/cm^2 for the mass range in Table 8. A 0.25" (0.635 cm) thick tank of the aluminum alloy has a density of 2.84 g/cm^3 so that the thickness of the tank is 1.803 g/cm^2. Thus the CPV represents a 34% to 51% increase in the relative tank thickness. To estimate the effect of the CPV on signal loss, the thickness of the vacuum tank alone was increased. The relative yield of the three detection methods as a function of the relative thickness of the vacuum tank is shown in Figure 5. The reduction in yield is between $\sim$3% and $\sim$6% depending on the actual thickness of the CPV and the detection.

Any additional losses due to the CPV in the downstream beam pipe have not been assessed by these studies.

3 Summary

Here I summarize the losses for the 2γPR detection method. The loss of signal due to a lack of the PR on the sides of the beam is $\sim$ 4%. A more realistic assessment of the active area of the PR reduces the yield by $\sim$ 21%. The loss due to a pure aluminum vacuum tank, flanges and beam pipe is $\sim$ 24%. If the structure is made entirely of the aluminum alloy, there is an additional $\sim$ 3% loss of signal. The CPV and its support structure further reduce the yield by $\sim$ 4%. If all these losses were independent, the 2γPR signal yield would be depleted by $\sim$ 46%. When all changes are performed simultaneously, the signal yield is reduce by $1 - (\tilde{L} \pm \delta L) = 43.6 \pm 0.8\%$ indicating there is some degree of 'double-counting'. In the CDR, a depletion of 14% was assumed.

2γPR	1γPR/1γCAL	1γPR/1γBV	Material
0.756 ± 0.003	0.726 ± 0.008	0.809 ± 0.004	nominal thickness for tank,flanges,etc.
0.917 ± 0.002	0.928 ± 0.001	0.909 ± 0.001	tank only
0.848 ± 0.007	0.792 ± 0.007	0.901 ± 0.001	tank, beam pipe only
0.833 ± 0.008	0.867 ± 0.003	0.886 ± 0.001	tank, pipe flange only
0.917 ± 0.002	0.914 ± 0.002	0.899 ± 0.001	tank, transition flange only
0.917 ± 0.002	0.928 ± 0.001	0.891 ± 0.001	tank, barrel flange base only
0.917 ± 0.002	0.928 ± 0.001	0.866 ± 0.005	tank, tall barrel flange only
0.968 ± 0.001	0.964 ± 0.001	0.978 ± 0.001	Al alloy/Pure Al

Table 5: The signal yield losses $\tilde{L} \pm \delta L$ for the three primary detection methods. The loss is evaluated with respect to the yield for no tank, flanges or beam pipe, except for the bottom row of this table. The top row of the table gives the losses for the nominal thickness of aluminum for the vacuum tank, flanges and beam pipe. The subsequent rows above the double horizontal line give the losses with different fractions of the entire assembly present. The losses due to the barrel flange are given separately for the "flange base" (z-extent 14.1 cm) and "tall barrel flange" (z-extent 6.35 cm), see Table 4. The bottom row of the table gives the relative loss of signal if the entire assembly is assumed to be Aluminum 2219-T87 (Table 7) compared to pure aluminum.

	$1-(\tilde{L} \pm \delta L)$		
2γPR	1γPR/1γCAL	1γPR/1γBV	Material
0.244 ± 0.003	0.274 ± 0.008	0.191 ± 0.004	nominal thickness for tank,flanges,etc.
0.083 ± 0.002	0.072 ± 0.001	0.091 ± 0.001	tank only
0.152 ± 0.007	0.208 ± 0.007	0.099 ± 0.001	tank, beam pipe only
0.167 ± 0.008	0.133 ± 0.003	0.114 ± 0.001	tank, pipe flange only
0.083 ± 0.002	0.086 ± 0.002	0.101 ± 0.001	tank, transition flange only
0.083 ± 0.002	0.072 ± 0.001	0.109 ± 0.001	tank, barrel flange base only
0.083 ± 0.002	0.072 ± 0.001	0.134 ± 0.005	tank, tall barrel flange only

Table 6: Similar information to Table 5 except that each column contains the relative reduction in signal yield $1-(\tilde{L} \pm \delta L)$.

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	91.5 - 93.8	Mn	0.2 - 0.4	Ti	0.02 - 0.1
Cu	5.8 - 6.8	Other, each	Max 0.05	V	0.05 - 0.15
Fe	Max 0.3	Other, total	Max 0.15	Zn	Max 0.1
Mg	Max 0.02	Si	Max 0.2	Zr	0.1 - 0.25

Table 7: The composition of the aluminum alloy "Aluminum 2219-T87" with a density of 2.84 g/cm^3 according to `matweb.com`. In the simulation the attenuation length is taken to be that of a mixture that is 92.65% Al and 7.35% Cu.

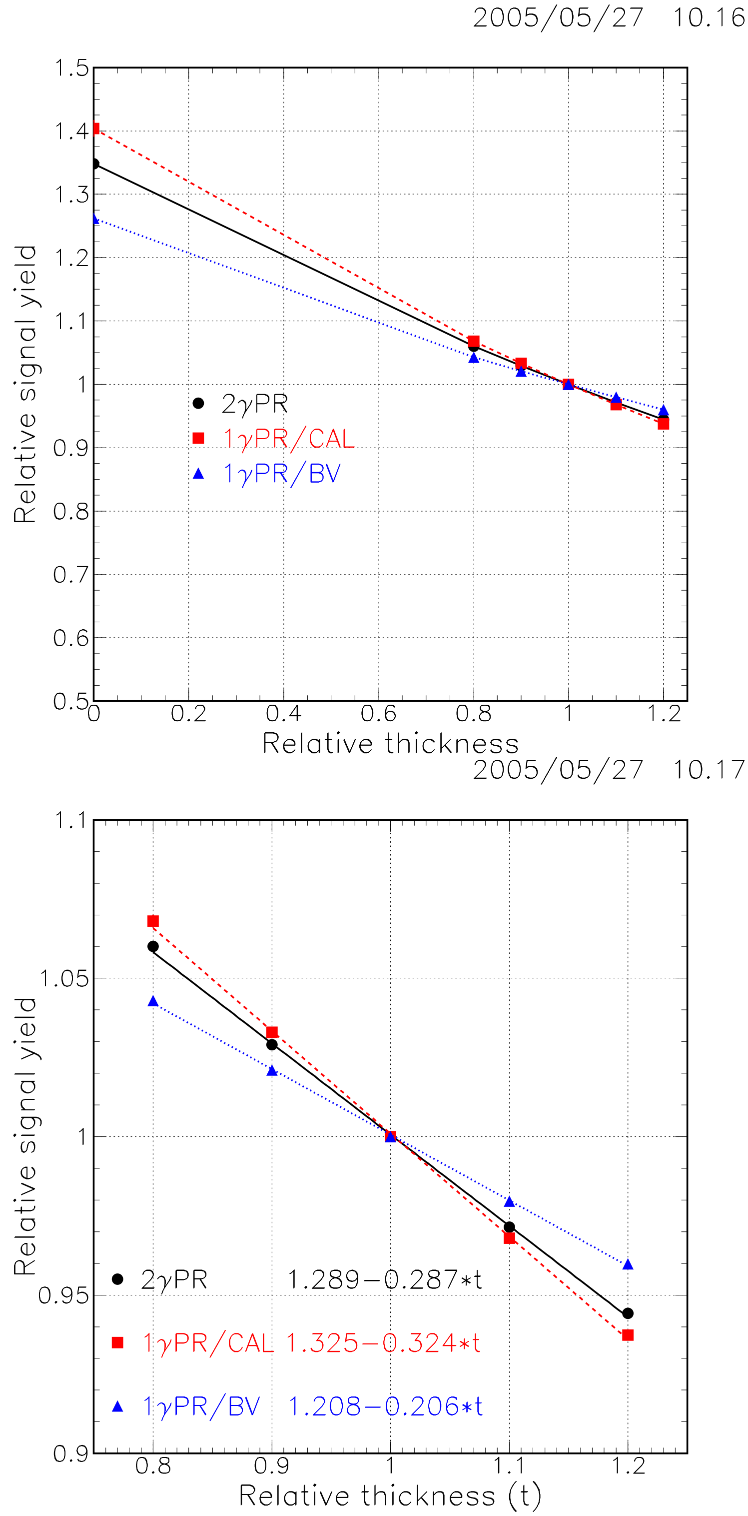

Figure 4: The relative signal yield as a function of the thickness of the vacuum tank, flanges and beam pipe relative to the nominal thicknesses given in Table 4. All materials are assumed to be composed of the aluminum alloy. In the top plot, the points are joined by straight lines to guide the eye. In the lower plot, the results of a linear fit are shown and the parameters are listed on the plot.

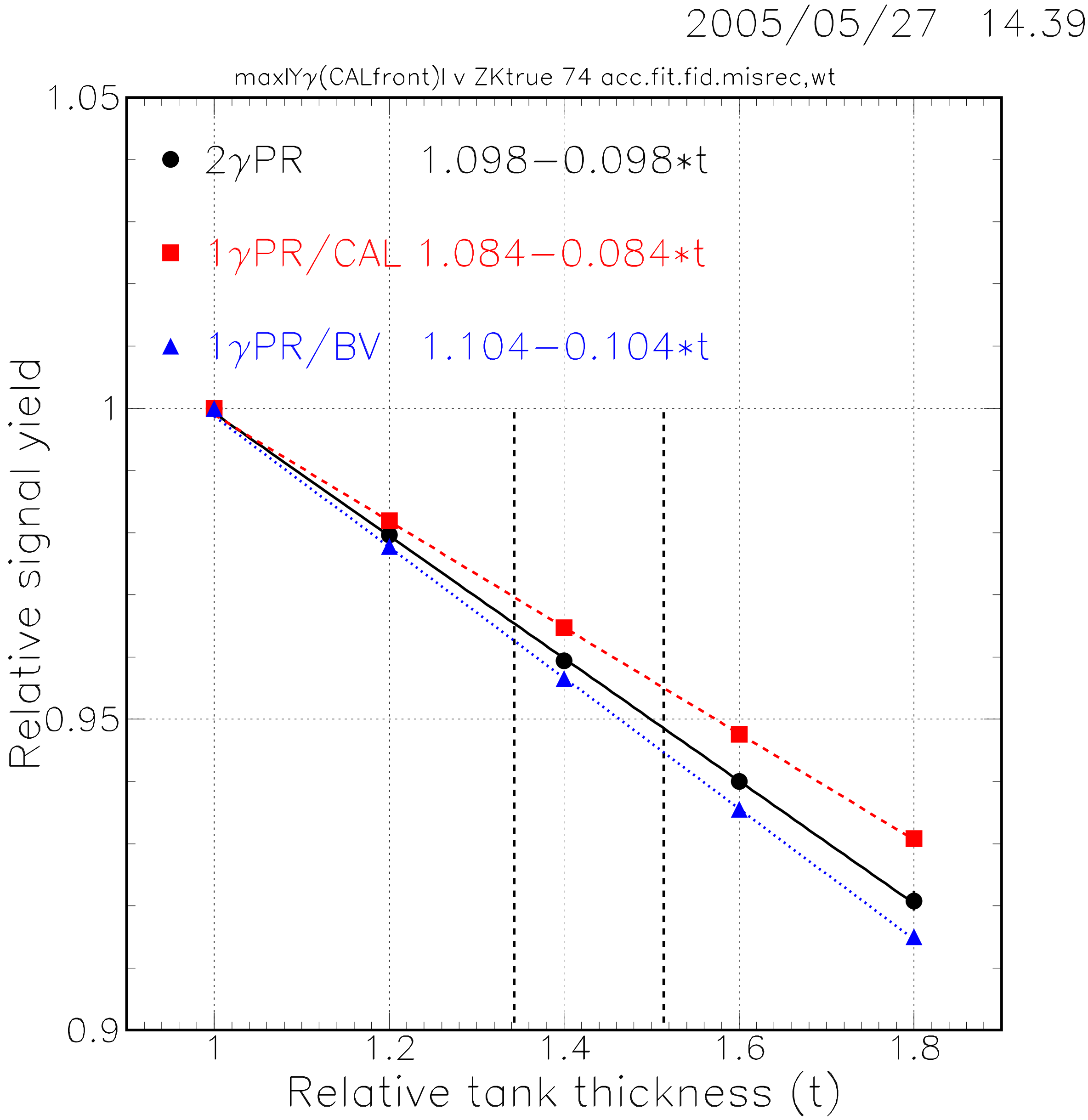

Figure 5: The relative signal yield as a function of the thickness of the vacuum tank relative to the nominal thickness given in Table 4. The flanges and beam pipe are fixed at the nominal thicknesses. All materials are assumed to be composed of the aluminum alloy. The results of a linear fit are shown and the parameters are listed on the plot. The vertical dashed lines show the approximate increase in thickness due to the CPV assuming that it is composed of the aluminum alloy.

Item	Mass
Scintillator	70 kg
Support structure	100 kg
PMT, cables, etc.	90 - 220 kg

Table 8: The estimated mass of the CPV elements inside the vacuum tank [9]. The total mass is estimated to be in the range 260 to 390 kg.

4 Acknowledgements

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References

[1] D.E. Jaffe, *FastMC User Manual*, KOPIO TN089, 20 Oct 2004.

[2] This is based on a 12 May 2005 e-mail from Toshio Numao.

[3] D.E. Jaffe, *Signal losses due to the vacuum vessel*, KOPIO TN024, 7 August 2001.

[4] Aleksey Sher, *FastMC study: Signal acceptance sensitivity to the aperture of the downstream beam hole*, KOPIO TN135, May 2005.

[5] Data from `http://physics.nist.gov/PhysRefData` as used by the PDG to produce Figure 23.12 of the Review of Particle Properties, Eur. Phys. J. **C**15, 1 (2000).

[6] Marvin Blecher did some studies showing that we could, in principle, recover photon conversions in the vacuum tank by detecting and reconstructing the e^+e^- pair in the PR. Perhaps this is feasible for the vacuum tank, but it seems doubtful that we would have accurate energy and angle information for a conversion in the 1" thick pipe flange.

[7] A. van der Schaaf, *KOPIO geometric acceptance - where do all the photons go?*, KOPIO TN095, 28 June 2004. "Position on detector" is defined in Figure 2.4.

[8] The information on Aluminum 2219-T87 was provided by Dana Beavis.

[9] This is based on a 6 April 2005 e-mail from Andries van der Schaaf.